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Relative Dust Emission Estimated From A Mini-Wind Tunnel

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Introduction

Measurement and modelling of fugitive dust emissions has become an increasing area of interest because of the effects of fugitive dust on visibility, air quality and the potential effect on human health (Pietersma *et al.* 1996). Direct measurements of dust emission can be achieved in various ways including using high volume air samplers down wind of a source or at source. Alternatively, wind tunnels have been used to measure the emission rate from agricultural fields and coal stockpiles. The portable wind tunnels used in most studies are similar in design to a number of "big" wind tunnels used in aeolian research. These big wind tunnels (BWT) have duct cross-sections in the order of 1m x 1m and working section lengths from 4 to 10m. BWT can have fully developed turbulent boundary layer from which measurements of surface roughness (z_0) and friction velocity (u_*) can be calculated using Pitot tubes (Raupach and Leys 1990). In comparison to these BWT, there are a few smaller tunnels. The most widely reported being that of Gillette (1978), which has a 0.15m x 0.15m cross-section and a 3m length and is reported to have a turbulent boundary layer.

Big wind tunnels have the disadvantage of being large and difficult to transport and generally require at least two people to operate. To overcome these issues, a mini wind tunnel (MWT) with 0.1m x 0.5m cross-section and a 1m working section was developed and used to estimate dust emissions (Zegelin *et al.* 1997). The flow in the MWT does not have a fully developed turbulent boundary layer, and as such, the wind profile can not be used to measure z_0 or u_* and subsequently calculate the equivalent wind velocity at 10 m height (u_{10}). To over come this, the ratio of dust flux in the MWT was compared to that in the DLWC big wind tunnel (Raupach and Leys 1990) at a range of wind speeds and where z_0, u_* and u_{10} were measured.

This paper presents estimates of relative dust emission for a range of iron ores and road surfaces using a mini-wind tunnel.

Materials and Methods

The design of the MWT is shown in Figure 1. The saltation introduction system (saltation silo) was not used in this study. The details of the DLWC BWT are reported in Raupach et al. (1990) and the sampling methods similar to the MWT and detailed in Leys et al. (1996).

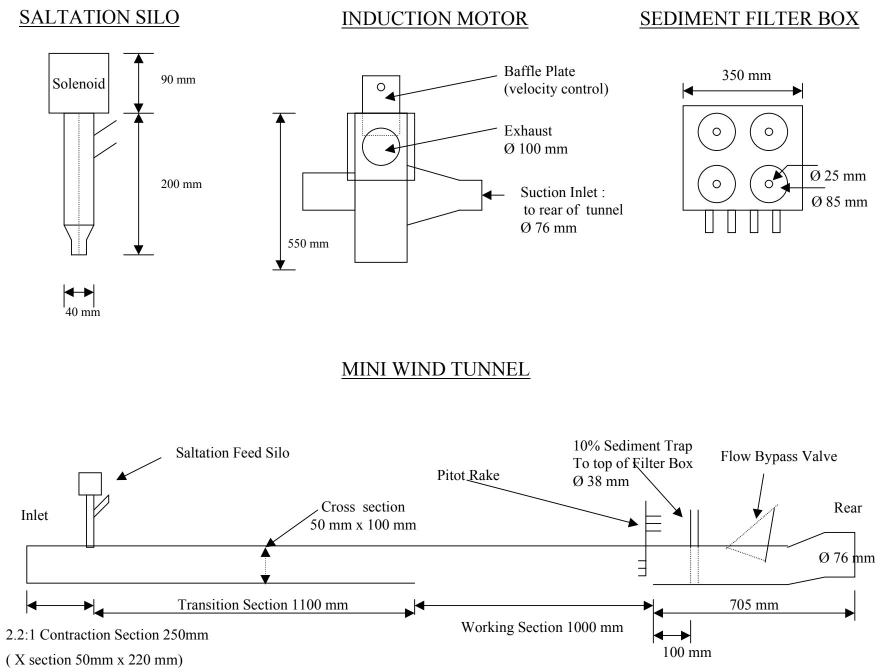

Figure 1. Schematic of mini wind tunnel (MWT)

In the MWT, five ores and three road surfaces were exposed to three to five wind speeds (each replicated three times for one minute), the resultant wind velocities were measured at three heights (15, 25, 35 mm) with Pitots then averaged (u, m/s) and erosion rates were measured with an integrating trap that sampled 10% of the tunnel air flow (E, g/m^2/s). Eroded sediment was captured on glass fibre filter papers (0.1µm pore size) in a sediment filter box. The sediment trap was quasi-isokinetic; ie the average speed of the tunnel was matched to the average speed of the inlet of the sediment trap. The particle-size distribution (PSD) was determined for the eroded sediment with a Coulter Multisizer using the methods of McTainsh et al. (1997). ORE C, was tested in the BWT and MWT. Erosion rates in both tunnels were calculated using equation 1.

$$E = m/(xyT) \qquad (1)$$

Where E = erosion rate [g/m^2/s], m = mass collected in trap, x = upwind fetch of 1 m for MWT and 4.2 m for BWT, y = trap width of 0.01 m for MWT and 0.005 m for BWT, and T = time 60 s

Dust fluxes were calculated using equation 2.

$$DF = E \times CFD \qquad (2)$$

Where DF = dust flux [g/m^2/s] and CFD = critical fraction of dust.

The CFD is the fraction of the eroded sediment that can be held in suspension by the wind for a particular u*. This fraction changes with u*, sediment density and air density and was calculated using the subroutines within the Wind Erosion Assessment Model (Shao *et al.* 1996) to determine the critical size of the suspension material and ranged from 30 and 37 µm.

Results and Discussion

The particle-size analysis of the eroded sediments indicated that the CFD ranged from 1.11 – 0.35 depending on wind speed and ore / surface. A comparison of the dust flux from the same ore (ORE C) is given in Figure 2.

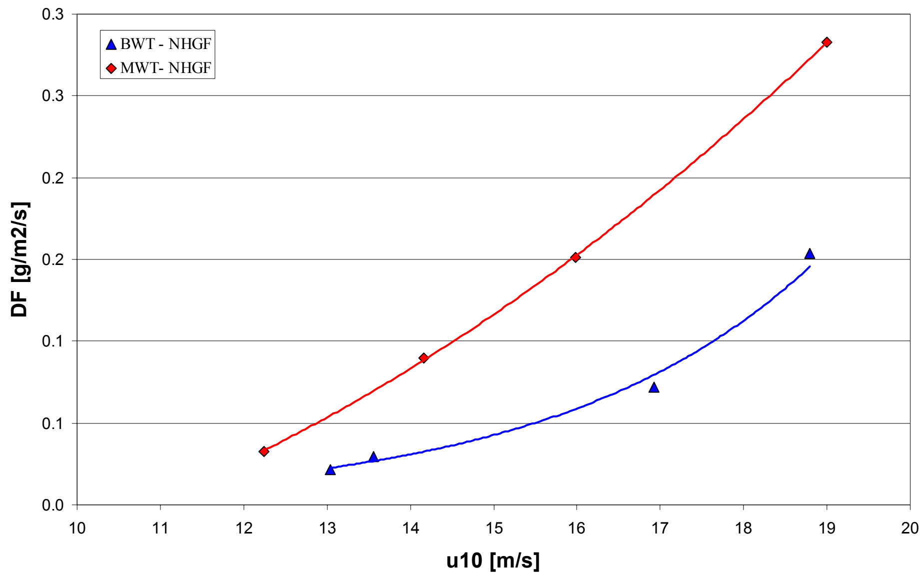

Figure 2. Dust flux (DF) from MWT and BWT for a range of wind speeds

The ratio of dust flux between the BWT and the MWT for the ORE C is described in equation 3.

$$DF_{BWT} = DF_{MWT} * 0.516738 - \frac{135740}{(u^3)^2} \qquad (3)$$

Where DF_{BWT} = dust flux equivalent [g/m^2/s] in DLWC wind tunnel, DF_{MWT} = dust flux [g/m^2/s] in mini wind tunnel, and u = wind speed. The MWT overestimates the DF compared to the BWT.

It was then possible to calculate an estimate of the dust flux from a wind speed measured at10 m height with the following assumptions:

- That the BWT / MWT DF relationship in Figure 2 established for ORE C can be used for all sites and ores. This is a fair assumption for this study as all the ores and surfaces were levelled before testing.
- That the wind speed correction from 10m height to wind tunnel free-stream is valid for all surfaces although only one correction factor been established for ORE C
- That the equations are limited to the wind speed range (u_{10}) of 8 to 20 m/s.
- That the results are for first minute of the specified wind speed, after which the DF would expect to decline, especially if the source of erodible material was limited.

Accepting these assumptions, estimates of the BWT equivalent dust flux (DF_{BWT}) can be made from the MWT results for a wind measured at 10m height by applying the following equations.

Site	*Equation*
Road - bulldust	$DF_{BWT} = 0.000306\ u_{10}^3 - 0.410156$
Ore A fines	$DF_{BWT} = 0.000058\ u_{10}^3 - 0.145065$
Ore B Fines	$DF_{BWT} = 0.000025\ u_{10}^3 - 0.029948$
Ore B sub fines	$DF_{BWT} = 0.000503\ u_{10}^3 - 0.757249$
Ore C	$DF_{BWT} = 0.000027\ u_{10}^3 - 0.042815$
Ore C sub fines	$DF_{BWT} = 0.001470\ u_{10}^3 - 2.602224$
Road - deposition material	$DF_{BWT} = 0.003367\ u_{10}^3 - 4.462010$
Road - gravel	$DF_{BWT} = 0.000464\ u_{10}^3 - 0.759889$

Where: DF_{BWT} = dust flux equivalent [g/m^2/s] in DLWC wind tunnel, and u_{10} = wind speed at 10m height

Conclusions

The use of a mini-wind tunnel to characterise the erosion rate of a surface in conjunction with particle-size analysis of the eroded sediment can be successfully used to determine the relative dust emission for a range of wind speeds and surfaces. By undertaking similar work with the large DLWC wind tunnel and deriving a ratio of dust emission between the two tunnels, it is possible to calculate indicative dust emissions for a range of ores and surfaces.

Dust emissions vary for the range of iron ores and road surfaces. Deposition material from conveyors that falls on roads (Road - deposition material) is extremely dusty and easily mobilised (DF_{BWT} = 15.18 g/m^2/s at a wind speed of 18 m/s when measured at 10 m height). The Ore C sub fines (ie Ore C with no fraction greater than 1 mm) is also very dusty (5.97 g/m^2/s at a wind speed of 18 m/s). The Ore B sub fines, Road - gravel, the Road - bulldust are moderately dusty (2.18 to1.37 g/m^2/s), with the remainder of the ores being less than 1.9 g/m^2/s. These dust emission rates would not be expected to persist for long periods because the sediment supply diminishes with time.

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